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Adaptive Radar

FREDERICK W. LEE AND MARK E. BURROUGHS

Airborne Radar Branch
Radar Division

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Frederick W. Lee and Mark E. Burroughs
Radar Division

Introduction

Future radars must operate in a world of ever increasing electromagnetic interference resulting in a degradation in system performance because of the presence of these undesired noise signals. The interfering signals may consist of intentional electronic countermeasures (ECM), unintentional radio frequency interference (RFI), or clutter returns. To combat the effects of ECM or RFI signals, several radar systems employ auxiliary receiving channels, known as sidelobe cancelers, to reject signals entering the radar receiver through the antenna sidelobes. To handle strong clutter returns, airborne surveillance radars use moving target indication (MTI) to make use of differences in Doppler shifts to distinguish between moving targets and "stationary" clutter. Although effective, both sidelobe cancelers and MTI systems suffer from critical performance limitations. Specifically, sidelobe cancelers are ineffective when ECM or RFI signals enter the radar receiver through the main beam of the antenna. In the case of MTI, clutter returns entering through the sidelobes of the antenna are shifted in Doppler, thereby becoming indistinguishable from Doppler shifts induced by target motion. To solve these problems, engineers at the Naval Research Laboratory (NRL) investigated a linear array system for airborne surveillance radars that detects the presence of interference sources and automatically adjusts to suppress these sources while simultaneously enhancing the reception of the desired radar returns. This type of system is known as an adaptive array radar.

Adaptive Array Radars

The use of an array of sensors for transmitting and receiving signals is becoming more common in modern radar systems. The Navy's E2-C Airborne Early Warning (AEW) radar system currently uses a linear array of sensors that allow for an increase in directivity and power capacity over a single sensor system. An adaptive array radar differs from this conventional array system by allowing dynamic control of the antenna beam pattern. This dynamic control is achieved by replacing the fixed beamforming network of the conventional system with a beamforming network that allows individual control of the antenna element weights. To control the weights, a real-time adaptive processor is needed. The purpose of the adaptive processor is to determine the optimum element weights that maximize the probability of detection for a fixed false alarm rate. This maximization of the probability of detection is equivalent to a maximization of the signal-to-noise ratio (SNR), where the signal is the desired radar return and the noise is the undesired interference.

The ability to maximize the SNR suggests that differences exist between the desired signals and the undesired noise that can be exploited. In the case of a radar system where the direction of arrival of the desired signals is known, spatial differences can be exploited by introducing beam pattern nulls in the directions of the undesired signals. Similarly, clutter returns are rejected by introducing nulls in the Doppler frequency domain. Research at NRL has demonstrated that

adaptive nulling of spatially distributed sources and Doppler frequency shifted clutter returns can be accomplished simultaneously by using space-time adaptive processing.

Proof of Concept

NRL's initial investigations of space-time adaptive processing involved an extensive computer simulation of a fully adaptive array radar. The model was of an active-pulse Doppler radar that simulated clutter returns and a selective number of spatially distributed interference sources. This computer model was used to investigate both transient and steady-state properties of a variety of adaptive algorithms.

Figure 1 shows that the nature of the adaptive space-time processor used in the computer simulation is best illustrated by examining its functional block diagram. Each antenna element in the system has a similar set of adaptive correction computers, multipliers, and a delay line that delays the element signal by one interpulse period. The two adders accumulate the outputs of the multipliers for each antenna element thereby forming the antenna beams. The front beam is formed from the summation of the weighted signals received during the current interpulse period. The back beam is formed from the summation of the weighted signals received during the previous interpulse period. Each beam has the ability to adaptively null spatially distributed interference sources and, by combining the two beams, nulls are formed in the Doppler frequency domain to simultaneously reject Doppler shifted clutter returns.

Figures 2 and 3 show typical outputs of the simulation in the unadapted and adapted response curves, respectively. The unadapted response is calculated by setting the output of the adaptive correction computers that drive the element weights to their quiescent or initial settings. The system then adapts to the particular scenario—in this case, stationary clutter—forming multiple nulls to attenuate signals that arrive from any angle with an apparent normalized target Doppler frequency of 0 Hz. Notice that this was accomplished without adversely affecting the main beam response at 90° for all other target Doppler frequencies.

Flight Test

After proving that space-time adaptive processing would work in a simulated environment, the next logical step was to test the feasibility of this processing against actual radar data. To accomplish this next critical step, NRL undertook an ambitious hardware development project to build a multichannel, real-time data recording system and then integrate this system with a specially modified airborne surveillance radar.

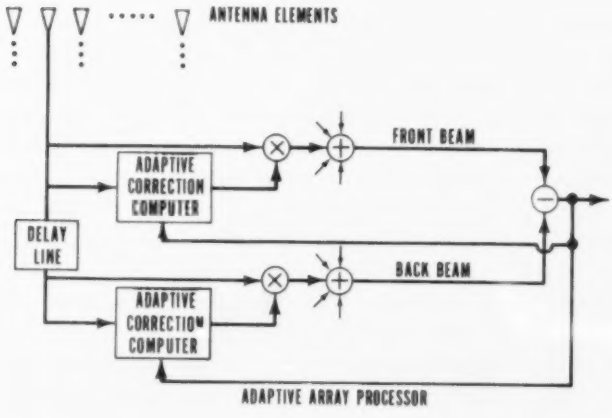


Fig. 1 — The adaptive space-time processor

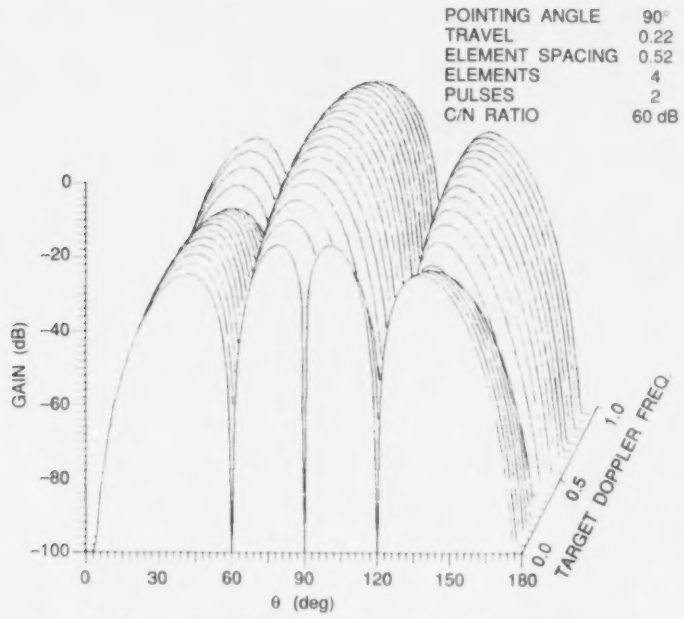


Fig. 2 — Unadapted response of adaptive space-time processor

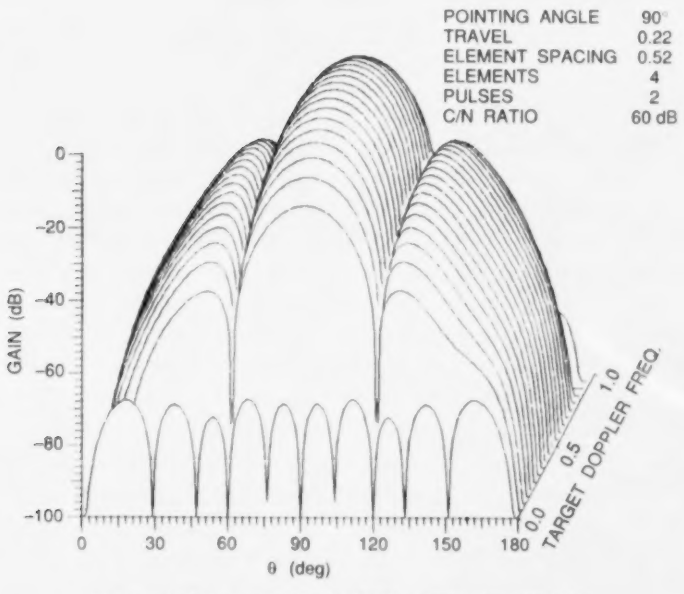


Fig. 3 — Adapted response of adaptive space-time processor

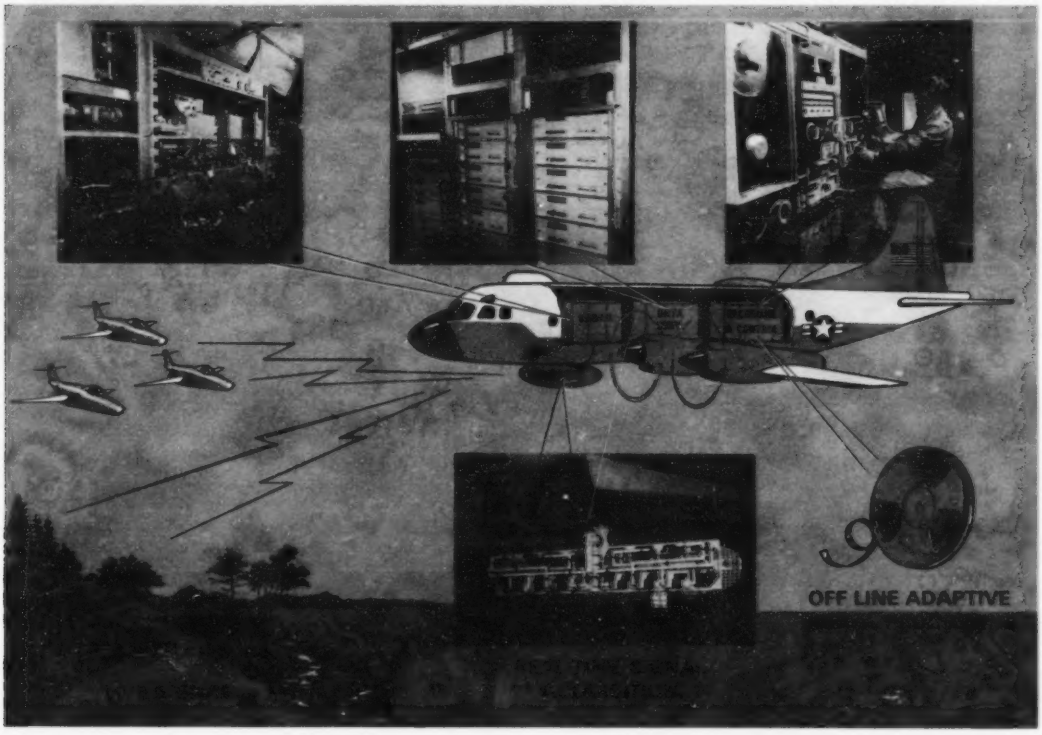


Fig. 4 — Space-time adaptive radar system layout

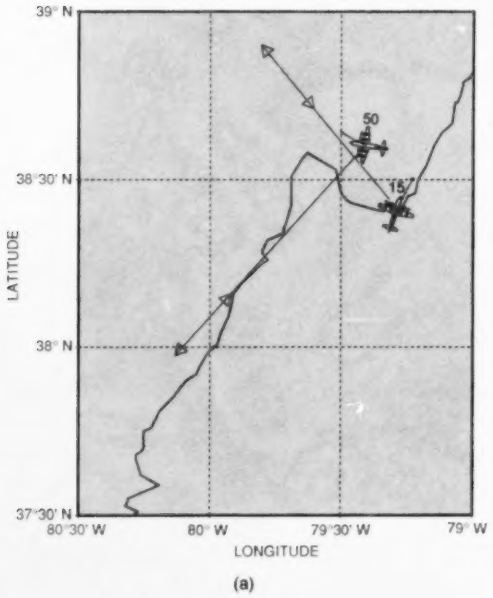
The modifications to the radar, performed under contract by the General Electric Company, were quite extensive. The original antenna system was replaced by a ten-element linear array of dipoles mounted in a 90° corner reflector. The end two dipoles were terminated leaving eight active elements with essentially identical element patterns. Each active element of the antenna was connected to a separate matched receiver that down-converted the received RF signals to the radar's intermediate frequency (IF). The eight IF channels were filtered to remove out-of-band signals, and then each channel was synchronously demodulated, yielding eight complex pairs consisting of inphase (I) and quadrature (Q) baseband video signals.

The result of such an elaborate receiving system is to preserve both the amplitude and phase of a channel's received RF signal in the channel's corresponding I and Q baseband video signals. Because video frequencies are lower than RF frequencies, the I and Q video could be more readily converted to digital data and stored for off-line processing. NRL designed and constructed a multichannel, real-time recording system to perform this function. The system consisted of a bank of 16 high-speed, analog-to-digital converters, one for each of the I and Q signals. The digital data were then synchronously buffered in a high-speed bulk memory array that was then spooled out to a magnetic tape recorder. The data on the magnetic tape could then be stored for off-line processing in a general purpose computer.

This system was flown aboard NRL's research aircraft (Fig. 4) and recorded a wide variety of live signal environments. Several of the flights used the radar strictly in a passive mode,

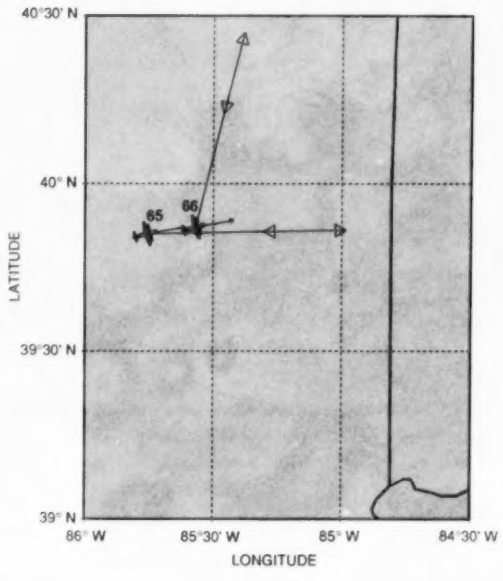
recording interference received from ground-based or airborne noise sources. On other flights, the radar actively captured returns from targets of opportunity while simultaneously being jammed by the noise sources. Because the data is in a recorded digital format, other jamming scenarios have been derived by superimposing one data set onto another, allowing for an even greater variety.

This database, which NRL maintains, also has one of the most complete sets of multichannel UHF land clutter data available to the research community. As an example, land clutter was obtained from such diverse regions as the Appalachian Mountains (near the border of Virginia and West Virginia) to the midwestern farmland of Indiana (Fig. 5). By examining the three-dimensional clutter spectra from these vastly different regions (Fig. 6), the difficulties in overland radar performance become evident. The differences in the dynamic structure of the clutter for the different regions, as well as the clutter variations of the same region for different antenna pointing angles, illustrate that the radar's ability to adapt to these changes is the key to successful radar performance in land clutter.

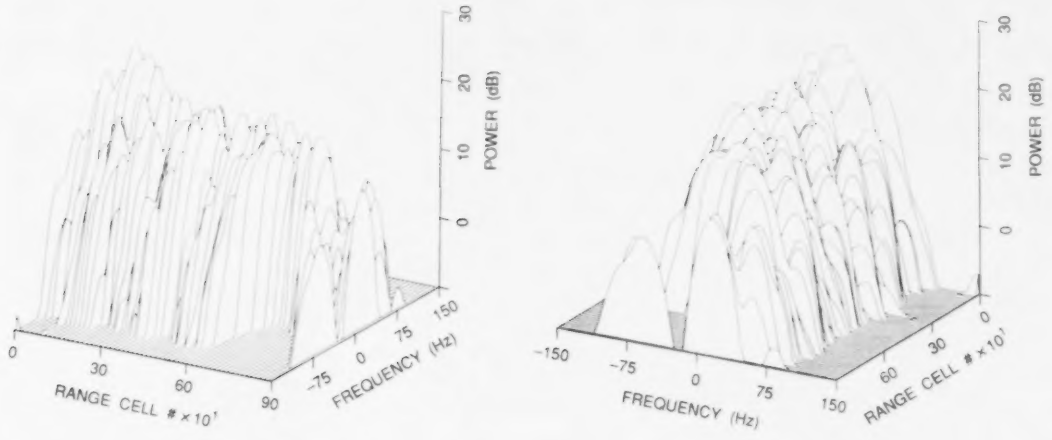


(a)

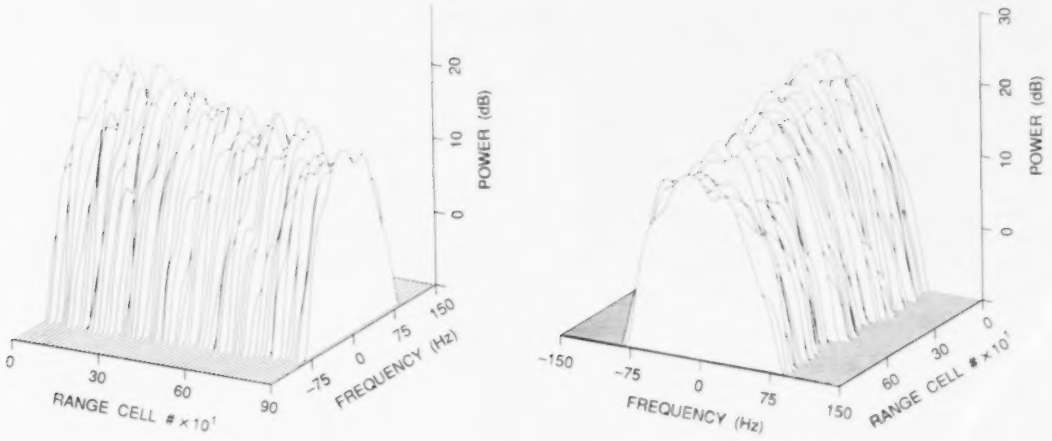
Fig. 5 — (a) Test area flight paths 15 and 50, (b) test area flight paths 65 and 66



(b)

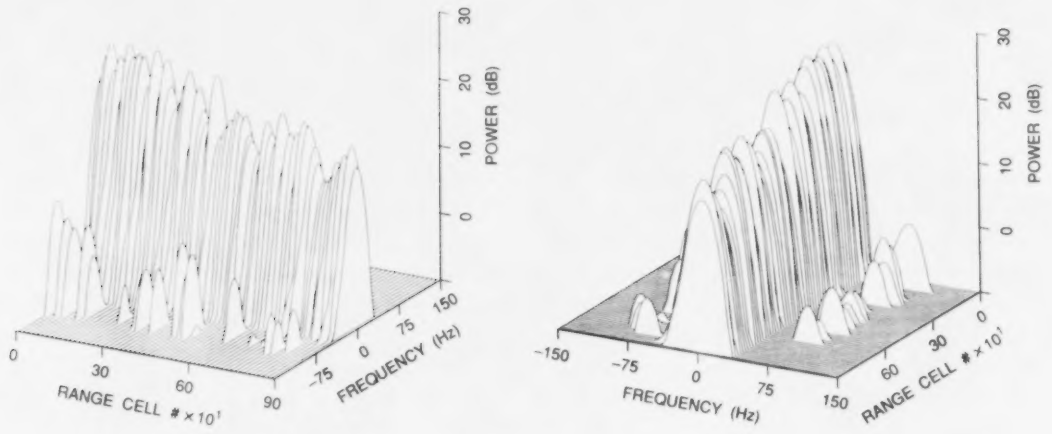


(a)

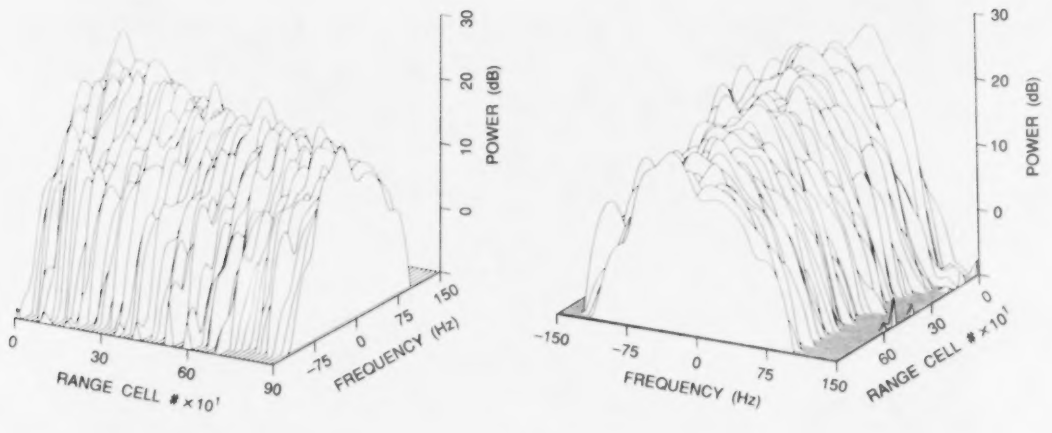


(b)

Fig. 6 — Land clutter spectra for: (a) flight path 15, 276 knots groundspeed, —67.7° antenna angle; (b) flight path 50, 224 knots groundspeed, —78.2° antenna angle; (c) flight path 65, 312 knots groundspeed, 8.7° antenna angle; and (d) flight path 66, 311 knots groundspeed, —65.8° antenna angle



(c)



(d)

Fig. 6 (Continued) — Land clutter spectra for: (a) flight path 15, 276 knots groundspeed, —67.7° antenna angle; (b) flight path 50, 224 knots groundspeed, —78.2° antenna angle; (c) flight path 65, 312 knots groundspeed, 8.7° antenna angle; and (d) flight path 66, 311 knots groundspeed, —65.8° antenna angle

Adaptive Processing Laboratory

On completion of the flight tests, the system was relocated into the Adaptive Processing Laboratory for advance hardware and algorithm development. A signal injection unit was constructed to emulate the live signal environment. The signal injection unit combines generated test targets with up to three spatially correlated RF noise sources to simulate the signal environment. The spatial correlation of the noise sources was accomplished by splitting (eight-to-one) the amplified output of each noise diode, yielding eight coherent channels for each of the three noise sources. A separate programmable phase shifter is then inserted into each of the paths followed by a three-to-one adder that combines an output for each of the three sources into a single output for each of the eight radar channels. By progressively varying the phase shifters, the signal injection unit generates noise signals that appear to come from three different angles of arrival with the test targets arriving from a fixed angle. The output of the signal injection unit is connected directly to the eight receivers with the rest of the laboratory system unchanged from that of the flight test system (Fig. 7).

The first advancement made in the laboratory was the development of a real-time adaptive digital beamformer. With recent progress made in the field of digital signal processing, it is possible to construct a system that applies the element weights in a digital format to the synchronous data stream coming out of the analog-to-digital converters. Also in the laboratory, a digital beamformer allows for an instantaneous analysis of the effectiveness of adaptive algorithms against contrived signal scenarios. In an operational system, the beamformer is one of the critical elements necessary for an adaptive radar. By demonstrating its capabilities in the laboratory, it is hoped that the inherent risk of implementing digital beamforming and thus, adaptive processing, is reduced to an acceptable level.

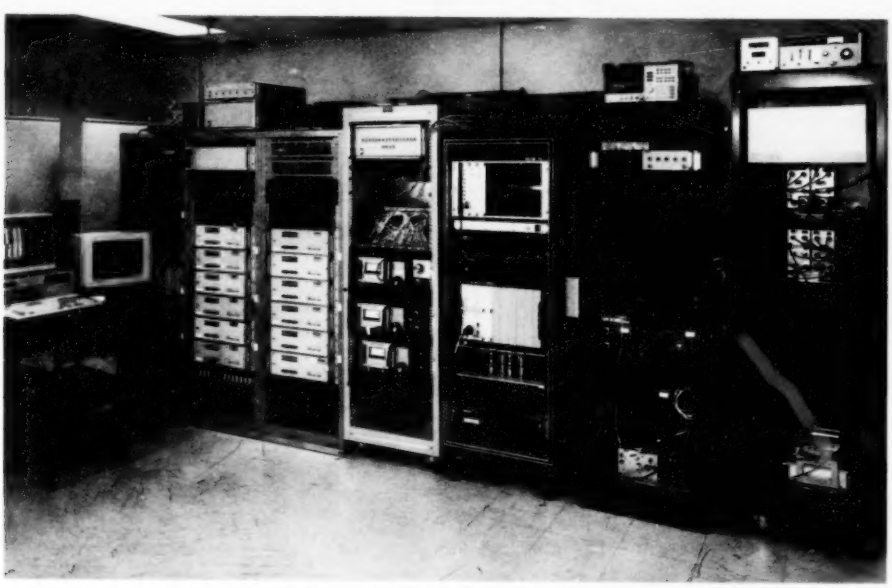


Fig. 7 — Adaptive Processing Laboratory

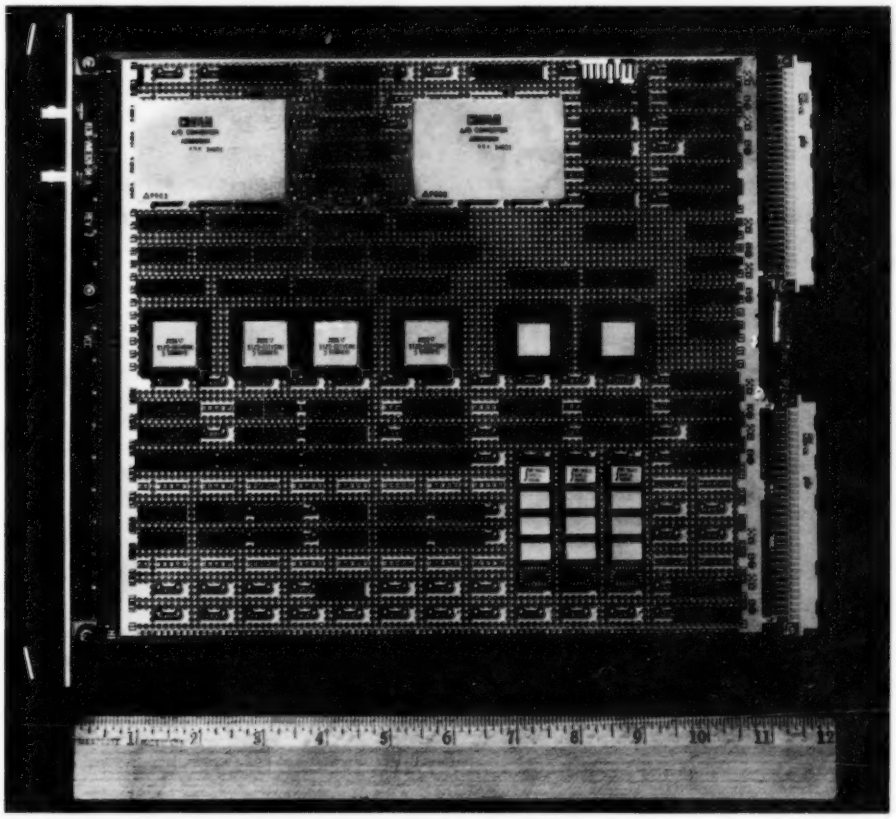


Fig. 8 — Digital equalization filter (prototype)

Currently, work is underway to develop an adaptive equalization filter bank to dynamically calibrate the radar channels to increase the overall cancellation ratio of the system. The prototype circuit (Fig.8) makes use of very large-scale integrated (VLSI) circuit technology yielding a computational performance of approximately 200 million operations-per-second. By operating these signal processing elements in parallel with each other, the overall system will exceed a billion operations-per-second. Along with the hardware developments, the Adaptive Processing Laboratory is being used to develop and refine adaptive algorithms, superresolution algorithms, and radar waveforms.

Conclusion

The use of adaptive radars has been demonstrated by NRL to be the key to successful operation of future Navy AEW radar systems. By using the NRL database, researchers continue to develop new and more effective adaptive algorithms that can be used in future radar systems. The development at NRL of real-time digital signal processors has demonstrated that the critical technologies necessary to field an operational adaptive radar system exist. The next crucial step is to fly an adaptive radar system in an operational environment to demonstratethe expected increases that adaptive processing adds to the detection

performance in dense clutter and jamming environments.

Acknowledgments

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THE AUTHORS

FREDERICK W. LEE received his B.S.E.E. degree from the University of Maryland, College Park, Maryland in 1986. He is currently working on his M.S.E.E. degree in communications at The George Washington University. Mr. Lee joined NRL's Radar Division in 1986, working for the Airborne Radar Branch on digitally controlled analog signal processors. Present research activities focus on real-time control system and digital signal processing. He is a member of the IEEE Acoustics, Speech, and Signal Processing Society.

MARK E. BURROUGHS received his A.A.E. degree (with high honors) from Prince George's Community College, Largo, Maryland, in 1982, and his B.S.E.E. degree (with honors) from the University of Maryland, College Park, Maryland, in 1984. In 1985, he joined NRL's Radar Division as an Electronics Engineer. Until 1988, his research centered on use of computer graphics to enhance radar imaging. Since then, his research has focused on real-time digital signal processing of radar data. Current work involves adaptive array beamforming.